Journal of Mechanical and Energy Systems (JMES)

Volume 1 Nomor 02 2024

STRENGTHENING STUDY OF ALUMINUM MATRIX COMPOSITES WITH SILICA ALLOY AND AGRICULTURAL WASTE (SIO_2/BA/RHA) FOR MOTORCYCLE BRAKE LININGS BY POWDER METALLURGY METHOD

Alek[1], Sukanto[2*], Erwanto[2], Ilham Ary Wahyudie[2], Husman[2]

[1] Student at Mechanical Engineering, Politeknik Manufaktur Negeri Bangka Belitung

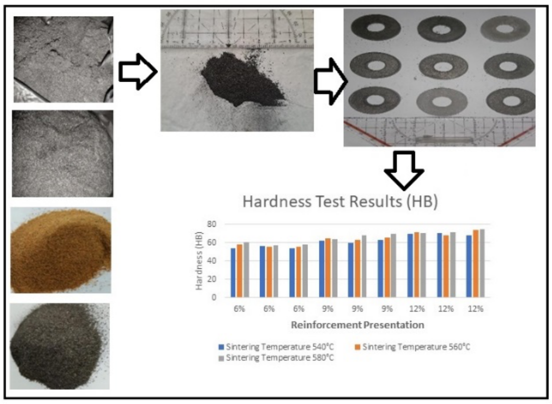
[2] Mechanical Engineering, Politeknik Manufaktur Negeri Bangka Belitung

Timah Raya *Street*, Air Kantung, Sungailiat, Bangka Belitung

*Corresponding author

sukanto@polman-babel.ac.id

Graphical abstract



Abstract

Brake linings commonly used in vehicles are mixed composites of asbestos-based materials that harm human health. Therefore, new alternatives are needed to meet the needs of materials to replace asbestos, such as aluminum matrix composites. However, silica alloy powder, rice husk ash, and bagasse ash contain some chemical components that can affect the mechanical properties of the composite, such as optimal density and hardness. This research aims to see the effect of the percentage of materials and sintering temperature on the density and hardness values of the resulting composite. The method used in this research is a full factorial design. In this study, the density testing process used the ASTM B962-17 standard reference and ASTM E110-14 as a standard reference for hardness testing with variations in the material composition of matrix is 94%, 91% and 88%, while the details of the strengthening percentage are SiO_2: RHA:BA = 1:1:1. The sintering temperature variations for all three are 540 °C, 560 °C, and 580 °C with a holding time of 7 minutes. The study showed that the highest density and hardness values produced were 2.415 g/cm³ and 75HB when the 12% reinforcement percentage composite was sintered at 580°C. In contrast, the reinforcement percentage and sintering temperature for aluminum matrix composites did not affect the density and hardness results.

Keywords: brake linings; AMC hybrid SiO_2 - RHA - BA; full factorial density; hardness

Article history: *Received, 6 Desember 2024, Received in revised: 22 Desember 2024, Accepted; 27 Desember 2024, Published online: 30 Desember 2024*

1. Introduction

Technology development in various fields is rapid, especially in the automotive field, motorcycle assembly manufacturers are developing engine performance capabilities and technology that support them increasingly rapidly. With the development of vehicle performance, an effective braking system and safety in driving are needed. Brake linings are one of the components found in every vehicle that functions to slow down and stop the speed of the vehicle [1]. Brake linings commonly used in vehicles are a composite mixture of asbestos-based materials bonded by polymeric binders and several other materials [2]. However, Asbestos is a mining material that is carcinogenic (cancer-causing substance), so it can cause problems for health [3]. Therefore, a new alternative is needed to meet these material needs. Theoretically, composites are materials formed by combining two or more materials to achieve a final material with mechanical properties superior to the constituent materials. The advantages of using composites include corrosion resistance, lightweight characteristics, attractive performance, manufacturing without machining processes, and suitability for several applications [4].

Aluminum matrix composites (AMC) are a type of composite where aluminum acts as the matrix or base material. At the same time, other reinforcements, such as fibers or particles, are also used in the mixture. AMC also has advantages such as low density, corrosion resistance, good elasticity, and mechanical tolerability, or it can be formed as needed [5]. The advantages possessed by this aluminum matrix composite are a reference for researchers to develop it as an alternative to asbestos brake lining material. Aluminum has superior characteristics, namely lightweight and corrosion resistance, making it suitable for use in various water environments (including seawater), oil, and other chemical compounds [6]. Silica sand (SiO_2) in Bangka Belitung, particularly from former tin mining areas and known as tailings silica sand, is available in large quantities. This resource is estimated to be spread over 64,255 hectares out of 124,838 hectares of former tin mining areas [7]. Previous research revealed that the soil in the area has a texture dominated by sand, with the composition of the sand fraction reaching 81-94%, dust content around 2-10%, and clay around 2-12% [8]. Rice husk ash (RHA) is a silica-rich material with distinctive characteristics that enable its use in various applications. In addition, RHA has several advantages, including economical production costs, its ability to suppress the formation of corrosive compounds such as aluminum carbide (Al_4C_3), and its potential as an environmentally friendly substitute for asbestos materials [9]. Bagasse ash is a waste produced after the milling process to separate the juice from the bagasse of the sugarcane plant. This waste, known as bagasse ash, comes from the sugar industry and contains lignin, cellulose, and hemicellulose fibers, which are by-products of sugarcane extraction. In general, bagasse has a composition of 52.67% water, 55.89% organic carbon, 0.25% total nitrogen, 0.16% P_2O_5, and 0.38% K_2O. When this bagasse is burned under controlled conditions, the resulting ash contains amorphous silica. After the combustion process, the silica (SiO_2) content in the ash increases to 64.65% [10].

The powder metallurgy method is used for the aluminum matrix composite manufacturing process. The primary process of the powder metallurgy method is divided into three stages: mixing matrix powder with reinforcing powder, the compression or pressing process, and the sintering stage [11]. However, the powder metallurgy method has several advantages compared to other processes, so the manufacture of composites with powder metallurgy technology has been increasingly developed recently [12]. High production speed because it can mass produce products, can produce products with complex shapes with small sizes, is easy to control product process parameters, and is able to produce products with more accurate dimensions [13]. Materials reinforced with SiC2/RHA/BA. For example, a study by Dylan et al. investigated the effect of volume fraction and sintering temperature on the density and hardness of recycled aluminum matrix composites, with an alloy reinforcement between silicon carbide and rice husk ash by varying the volume fraction of the reinforcement by 10%, 15%, and 20% and the sintering temperature was varied at 550°C, 580°C, 610°C. The highest density value in the sample with a 90% volume fraction is 1.72 g/cm3, and the highest hardness value is 40 HB [14]. In addition, there is research on the effect of compaction pressure and sintering temperature variations on the density and hardness of AMC reinforced with BA and Al2O3. Density testing obtained results with the highest value of 1.59 gr/mm3, while hardness testing obtained the highest results, rated at 42.76 HRB; the highest value was found at a compaction pressure of 6400 Psi.[15].Based on previous research, it is known that the treatment process applied to fibers used for composite reinforcement affects the composite's mechanical properties, including the composite material's tensile strength. Furthermore, using citronella plant fibers as composite reinforcement still needs to be improved. Therefore, this study will investigate citronella fiber-reinforced composites by applying chemical treatments to citronella fibers using natural compounds, namely coconut shell liquid smoke and turmeric solution, to examine the effects of these treatments on the tensile strength of the resulting composite. Based on previous research, it is known that the processing process applied to silica sand, rice husk ash, and bagasse ash used for aluminum matrix composite reinforcement affects the composite's mechanical properties, including the composite material's density and hardness. Furthermore, silica sand, RHA, and BA as composite reinforcement still need to be improved. Therefore, this study will examine aluminum matrix composites reinforced with silica alloys and agricultural waste by applying powder metallurgy methods to assess the density and hardness values of the resulting composites.

This research will involve recycled aluminium as a composite matrix in binder and armor-reinforced silica alloy silica and agricultural waste; this research offers new insights to increase awareness of environmentally friendly composites. The novelty of this research lies in several key aspects related to silica alloys, rice husk ash and bagasse ash as reinforcement in composite materials:

The use of silica alloys and agricultural waste as reinforcement, such as silica sand, rice husk ash, and bagasse ash, is relatively less explored in the context of composite reinforcement. This study contributes to understanding the mechanical properties, especially the density and hardness of composites, which could be a new application of aluminium matrix composites.

- The use of silica alloys and agricultural waste as reinforcement, such as silica sand, rice husk ash, and bagasse ash, is relatively less explored in the context of composite reinforcement. This study contributes to understanding the mechanical properties, especially the density and hardness of composites, which could be a new application of aluminium matrix composites.
- Comparison of material composition and sintering temperature: this study explores the impact of parameters on the mechanical properties of composites. The focus on density and hardness provides a deeper understanding of how the powder metallurgy process factors in the optimization of agricultural waste-reinforced composites.
- Full Factorial Design Method: The full factorial design method is used to study the effects of two factors (material composition and sintering temperature) on the density and hardness of composites, adding a structured experimental approach. The combination of these variables and their effect on mechanical properties has yet to be widely studied in brake linings.

In summary, the novelty lies in the use of silica, rice husk ash, bagasse ash in the powder metallurgy process, and the full factorial design that evaluates their combined effects on material composition and sintering temperature, contributing new knowledge to the research of agricultural waste reinforced composites.

2. Material and Method

The composite was moulded using recycled aluminium powder with silica sand, rice husk ash and bagasse ash reinforcement. Then, the aluminium material and reinforcement are mixed using a ball mill machine, which mills for 6 hours. This mixing produces a more uniform, and dense compaction to improve the bond quality between particles. The material was compressed with a 2-way hydraulic press with a pressure of 6000 Psi and held for 20 minutes. The hot compaction process takes place at 350°C in a ring-shaped mould having an inner diameter of 20 mm and an outer diameter of 50 mm, then tested for density and hardness tests.

2.1. Material

Supporting equipment in this research includes digital scales, a ball mill machine, a two-way hydraulic press, a mould, a thermogun, a thermocouple, an oven, a measuring cup, a portable hardness tester, and a density tester for composite testing. The materials used in this research are recycled aluminium powder, silica sand, rice husk ash and bagasse ash. Silica sand, rice husk ash, and bagasse ash reinforce materials in the composite, while recycled aluminium powder acts as a matrix for binding. The materials used in this study are depicted in Figure 1 below. These materials are crucial to ensure accurate results when testing the resulting composites.

(a) (b) (c) (d)

Figure 1. Recycled aluminium powder (a), Silica sand (b), Rice husk ash (c), Bagasse ash (d)

- Physical and mechanical properties

Aluminum has good moldability, machinability, casting ability, and corrosion resistance. Its physical and mechanical properties make it a candidate for a composite matrix. This recycled aluminium has an element content level of 83% aluminium, 10% silica, 2.67% copper, 1% nickel, 0.85% Zn and 2.48% other impurities. Therefore, recycled aluminium for the matrix in this composite has physical properties close to the physical properties of Aluminum Si Alloy with a small percentage of copper and magnesium, as shown in Table 1, while the mechanical properties are as shown in Table 2.

Table 1. Aluminium physical properties [16]

Physical properties	AlSi10Mg ≈ Al83%/10Si
Density	2,67 gram/cm3
Melting point	570 – 590 °C
Thermal Conductivity	120 – 180 W/mK
Coefficient of Thermal Expansion	20 x 10-6 k-1 90 -100 ˚C)

Table 2. Mechanical properties of standardized and non-standard grades [17]

Condition	Tensile strength [MPa]	Yield strength [MPa]	Elongation at break [%]	Brinell hardness
Die cast, cast condition	240	140	1	70

2.2 Method

This research uses the powder metallurgy method; the steps of the powder metallurgy process are mechanical alloying and solidification of metal powder through pressing and sintering [12]. The alloying and mixing of powders is carried out using a ball mill machine. The parameters used in this process include a Ball Powder Weight Ratio (BPR) of 10:1, an engine rotation speed of 90 Rpm, and a grinding time of 6 hours. In this study using a powder mixture with a ratio of 88% Al: 12% (SiO_2, RHA, BA), 91% Al: 9% (SiO_2, RHA, BA), 94% Al: 6% (SiO_2, RHA, BA) with the weight of each sample being 35-40 grams. The powder was weighed with digital scales with an accuracy of 0.01.

Furthermore, the powder was mixed with one mixing weighing 360 grams. The powder was put into a horizontal ball mill machine tube, which contained small steel balls with a diameter of 30mm and 25mm, with the weight of each ball being 111.18 grams and 65.96 grams. The balls have an average hardness of 61 HRC and 58.2 HRC. After the mixing process is complete, compaction and two-way pressing are carried out using a hydraulic press that has been prepared. The machine has upper and lower hydraulic systems and a pressure gauge to monitor the applied pressure. Two-way pressing provides an advantage in more even pressure distribution between the top and bottom surfaces. The hot compaction method applies pressure to the sample and heating the powder. The mould used is ring-shaped with an inner diameter of 20 mm and an outer diameter of 50 mm. The sintering process aims to improve the inter-particle bonding of the powders. The verified samples were put into the oven when the process was executed. In the heating process, the samples were given temperatures of 540°C, 560°C and 580°C and a holding time of 7 minutes. The selection of the sintering temperature refers to the theory that states that, in general, sintering is carried out at 90% of its melting temperature [18], and considering that the matrix powder is recycled aluminum, which generally has an increased melting temperature [14]. After sintering, the samples are removed from the oven and cooled at room temperature.

-Sample

In this study, the preparation of density test specimens with ASTM B962-17 [19] standards is based on the principle of Archimedes' law and ASTM E110-14 [20] standard hardness test by visually seeing whether the samples that have been made have defects such as imperfect shapes (eroded), cracking and breaking. If the sample that has been made is in a test-worthy condition, it directly enters the testing stage, but if the sample still has defects and is not as expected, then the re-moulding process is carried out on the sample from the initial stage.

The process of making aluminium matrix composite specimens reinforced with silica sand and agricultural waste is as follows [14]:

1. Prepare tools and powders that have been mechanically alloyed.
2. Prepare the mould and put it into the hot compaction machine
3. Pour the powder into a mould that has been weighed 35-40 grams.
4. Turn on the thermocouple control and heat the mould to 350°C.
5. Monitor the temperature on the thermocouple monitor that can be turned off and turn on the switch
6. Perform up and down presses on the hot compaction machine with a pressure of 6000Psi.
7. Hold time for the pressing process for 20 minutes
8. Carefully remove the specimen from the mould.
9. Leave the specimen at room temperature for two weeks, to make the microstructure more stable and the composite is ready for testing.

Figure 2. Specimen

- Sample test
  - Density sample test

  In this study, density testing was carried out using a density tester that refers to Archimedes' law with test standards using ASTM B962-17. The test procedure is as follows:

  1. Prepare all equipment and specimens needed for the density testing process.
  2. Calibrate digital scales and test equipment accordingly to ensure accurate measurements.
  3. Place the specimen securely in a container filled with distilled water.
  4. Ensure that the scale pendulum and thread hold the specimen in place.
  5. Monitor the results displayed on the scale monitor after 10 minutes of immersion.

  - hardness sample test

  In this study, hardness testing was done with a portable hardness tester with a pressing load of 2 kg and a ball-shaped indenter with a diameter of 2 mm. Hardness testing was conducted using the ASTM E110-14 test standard. The test procedure is as follows:

  1. Prepare all equipment and specimens required for the hardness testing process.
  2. Calibrate a suitable portable hardness tester to ensure accurate measurements.
  3. Place the specimen securely on a flat area.
  4. Place the nozzle on the surface of the sample and press.
  5. Monitor the results displayed on the test equipment monitor screen.
  6. Do this 3 times at different points.

- Full factorial Design Method

The full factorial method thoroughly evaluates the effects of factors and their interactions in experiments. It is a regression approach used to model the relationship between the response variable and one or more independent variables. The advantages of the full factorial design include its ability to provide comprehensive information on the main effects and interactions between the factors under study.

Table 3. The Full factorial Design

No.	Response Variable		
	Reinforcement Presentation (%)	Sintering Temperature (◦C)	Quantity of Specimens
1	6	540	3
2	6	560	3
3	6	580	3
4	9	540	3
5	9	560	3
6	9	580	3
7	12	540	3
8	12	560	3
9	12	580	3

This research uses a complete factorial design method, with the percentage of reinforcement and sintering temperature as factors that have three levels. The levels between parameters can be multiplied, and each combination is tested a total of n times. Details of this treatment and experimental combination are shown in Table 3.

- Analisis of varian (ANOVA)

Analysis of Variance (ANOVA) is a method to test the hypothesis of similarity of means of three or more populations. The analysis of repeated measurement data is carried out to investigate whether there are significant differences. To evaluate the factors A, B, the interaction between A and B, total, and error can be calculated using the following equation:

$$SS_A = \frac{1}{bn}\sum_{i=1}^{a} Y^2 - \frac{Y^2}{abn} \tag{1}$$

$$SS_B = \frac{1}{an}\sum_{j=1}^{a} Y^2 - \frac{Y^2}{abn} \tag{2}$$

$$SS_{AB} = \frac{1}{n}\sum_{i=1}^{a}\sum_{j=1}^{b} Y^2 ij - \frac{Y^2}{abn} - SS_A - SS_B \tag{3}$$

$$SS_T = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} Y^2 ijk - \frac{Y^2}{abn} \tag{4}$$

$$SS_E = SS_T - SS_A - SS_B - SS_{AB} \tag{5}$$

The ANOVA table for a fullfactorial design summarizes the source of variation, degrees of freedom (DF), the sum of squares (SS), mean square (MS), and F-value. For the fullfactorial design of this study, the ANOVA table is organized as follows:

Table 4. ANOVA fullfactorial design

Source of Variation	SS	DF	MS	F_{value}
A	SS_A	$\boldsymbol{n-1}$	$\boldsymbol{MS_A = \frac{SS_A}{DF_A}}$	$\boldsymbol{\frac{MS_A}{MS_E}}$
B	SS_B	$\boldsymbol{n-1}$	$\boldsymbol{MS_B = \frac{SS_B}{DF_B}}$	$\boldsymbol{\frac{MS_B}{MS_E}}$
AB	SS_{AB}	$\boldsymbol{(a-1)(b-1)}$	$\boldsymbol{MS_{AB} = \frac{SS_{AB}}{DF_{AB}}}$	$\boldsymbol{\frac{MS_{AB}}{MS_E}}$
Error	SS_E	$\boldsymbol{ab(n-1)}$	$\boldsymbol{MS_E = \frac{SS_E}{ab(n-1)}}$	
Total	SS_T	$\boldsymbol{N-1}$		

3. **Result and Discussion**

The mixing process results were achieved using the mechanical alloying method for 6 hours.

Figure 3. Mechanical alloying results

Based on the picture, using the mechanical alloying method, the mixing results will be more homogeneous, forming interlocking bonds when carried out in the sintering process. The results of the Particle Size Analyzer (PSA) test conducted at the FMIPA-KIMIA laboratory, Brawijaya University, obtained a value for the average distribution size of 10 grams of powder is D50: 144.28µm, which can be seen in the graph of the test results in Figure 4. This study uses a ring-shaped sample with an outer diameter of 50 mm and an inner diameter of 20 mm, with a sample height of 8mm weighing 35-40 grams in each sample.

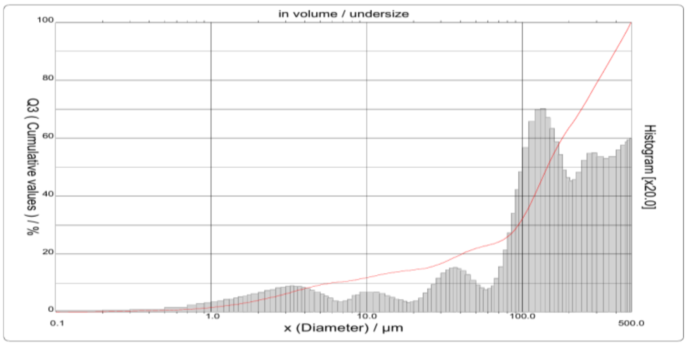


Figure 4. The mixing process results were achieved using the mechanical alloying Distribution graphic of D50:144.28 powder with particle size analyzer (PSA) testing.

Figure 5. Results of hot compaction results with two-way pressing

- Density and hardness test data
    - Density test data

After performing the density and hardness tests, the test results provide information about the maximum density value obtained before failure. Although 3 samples per parameter variation may be sufficient in some cases, it may not always provide the most reliable results. Table 1 and 2 shows the density and hardness test results, which were used for further analysis of the material's mechanical properties.

Based on the density test data, it is evident that the percentage of material after sintering significantly affects the density of the material. The highest value, 2.415 g/cm³, was achieved in the sample using a 12% reinforcement percentage and a sintering temperature of 580°c. In contrast, the sample using a 6% reinforcement percentage and 540°c sintering temperature produced the lowest density value of 1.783g/cm³. The increase in value is caused by increasing the density value of the specimen. In the sintering process, there can be changes in microstructure, such as a decrease in the number of pores and a reduction in pore size to increase the density value, and the gas or air trapped in the specimen evaporates so that the density value increases. Density helps to increase heat absorption and release capacity, aiming to prevent performance loss due to overheating. These results provide important insights for determining the optimal reinforcement and sintering temperature percentage to achieve the maximum material value.

Table 5. Density test results

No	Reinforcement Presentation (%)	Sintering Temperature (°C)	Density (g/cm³)			Average (g/cm³)
			1	2	3	
1	6	540	1,783	1,733	1,829	1,781
2	6	560	1,811	1,797	1,805	1,804
3	6	580	1,834	1,808	1,810	1,817
4	9	540	1,815	1,850	1,865	1,843
5	9	560	2,018	2,013	1,835	1,955
6	9	580	2,007	1,954	2,092	2,017
7	12	540	1,994	2,008	2,295	2,099
8	12	560	2,218	2,171	2,075	2,154
9	12	580	2,415	2,220	2,291	2,308

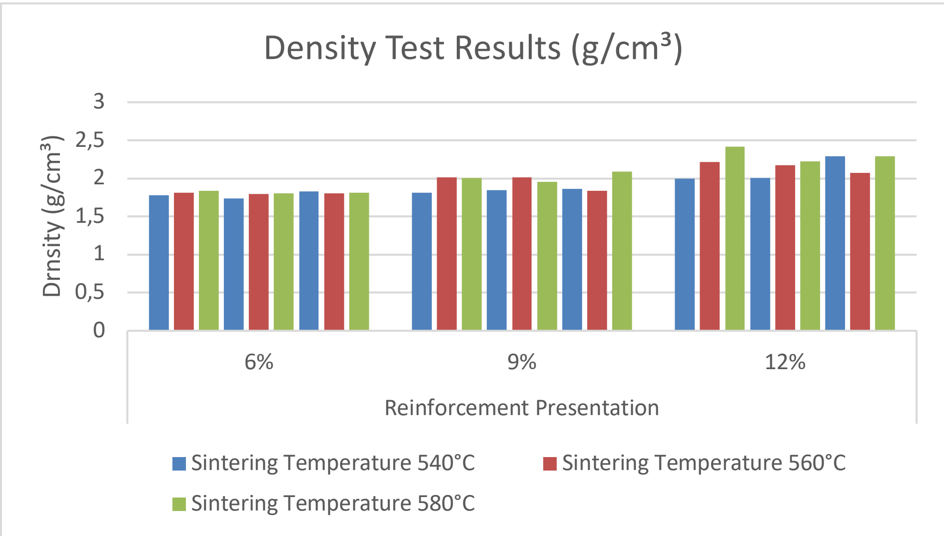


Figure 6. The graphic of the density test results

- Analysis of Variance Density

Analysis of variance (ANOVA) was performed by calculating the sum of squares of the experimental data based on Table 5. Calculating the sum of squares includes several important components using equations (1) to (5). The calculated components include the sum of squares for factor A, the sum of squares for factor B, the sum of squares for the interaction between factors A and B, the sum of errors, and the total sum of squares. After all the components of the sum of squares were calculated, the results were entered into the ANOVA table. This ANOVA table is used to identify the significance of the effect of each factor and its interaction with the response variable, as well as to determine the proportion of data variability explained by the model.

$$SS_A = \frac{1}{9} \times \frac{((1{,}783 + 1{,}811 + \cdots + 1{,}810)^2 + (1{,}815 + 2{,}018 + \cdots + 2{,}092)^2 + (1{,}944 + 2{,}218 + \cdots + 2{,}291)^2)}{9} - \frac{53{,}346^2}{27} = 0{,}69012$$

$$SS_B = \frac{1}{9} \times \frac{((1{,}783 + 1{,}733 + \cdots + 2{,},295)^2 + (1{,}811 + 1{,}797 + \cdots + 2{,}075)^2 + (1{,}834 + 1{,}808 + \cdots + 2{,}291)^2)}{9} - \frac{53{,}346^2}{27} = 0{,}08831$$

$$SS_{AB} = (1{,}783^2 + 1{,}733^2 + \cdots + 2{,}291^2) - \frac{53{,}346^2}{27} - 0{,}58403 - 0{,}06386 = 0{,}03124$$

$$SS_T = (1{,}783^2 + 1{,}733^2 + 1{,}829^2 + \cdots + 2{,}291^2) - \frac{53{,}346^2}{27} = 0{,}93541$$

$$SS_E = 0{,}93541 - 0{,}69012 - 0{,}08831 - 0{,}03124 = 0{,}1257$$

The results of calculating the sum of squares were entered into the ANOVA table for further analysis. This table includes the sum of squares for factors A and B, the interaction between the two, and the error. The sum of squares calculates the values of degrees of freedom, mean square, and F-value. The F-value is used to assess the significance of the effect of each factor and its interaction with the response variable. This process helps explain the extent to which the applied model can describe the variability of the data.

Table 6. Analysis of Variance Density

Source of Variation	SS	Df	MS	F_{value}	F_{table}
A	0,69012	2	0,345061	49,41	3,55
B	0,08831	2	0,044157	6,32	3,55
AB	0,03124	4	0,007809	1,12	2,93
Error	0,1257	18	0,006983		
Total	0,93541	26			

The significance level used is 5% or 0.05. Based on Table 6, the ANOVA density results show that the calculated F value for the percentage of reinforcement is greater than the F table value. The calculated F value for the percentage of reinforcement is 49.41, while the F table value is
3.55. Thus, the decision is that H1 fails to be rejected, which means that the percentage of reinforcement significantly affects the density value of the composite. Furthermore, the calculated F value for sintering temperature is greater than the F table value. The calculated F value for sintering temperature is 6.32, with the same F table value of 3.55. This result also shows that the decision H1 fails to be rejected, meaning the sintering temperature treatment significantly affects the density.

Furthermore, the interaction between the percentage of reinforcement and sintering temperature treatment showed a calculated F value smaller than the F table value. The calculated F value for the interaction between these two factors was 1.22, with an F table value of 2.93. Based on these results, the decision is that H0 fails to be rejected, meaning that the interaction between the percentage of reinforcement and sintering temperature has no significant effect on the density value. This ANOVA concludes that both the reinforcement percentage and sintering temperature significantly affect the density tested. In contrast, the interaction between the reinforcement percentage and sintering temperature does not significantly affect the density values.

- Hardness test data

Based on Table 7, the hardness test data, it is evident that the percentage of material after sintering significantly affects the density of the material. The highest value, 75HB, was achieved in the sample using a sintering temperature of 580°c. Conversely, the sintering temperature of 540°c produced the lowest hardness value of 53.7HB. The increase in value is caused by increasing the hardness value of the specimen, and the sintering process can increase the density caused by the formation of bonds between particles in the powder through atomic diffusion. A strong chemical bond forms, thereby strengthening the overall structure of the material and increasing its hardness. These results provide important insights for determining the optimal percentage of reinforcement and sintering temperature to achieve the maximum hardness value of the material. Of course, excessive hardness can cause a decrease in braking performance. Conversely, brake linings made from materials with too low a hardness may not be as durable or effective in generating the friction required for braking.

Table 7. Hardness test results

No	Reinforcement Presentation (%)	Sintering Temperature (°C)	Kekerasan (HB)			Average (HB)
			1	2	3	
1	6	540	54	56,3	53,7	54,6
2	6	560	58,3	55,6	56	56,6
3	6	580	60,6	57,6	58	58,7
4	9	540	62	60	63,3	61,7
5	9	560	65	63,6	66	64,8
6	9	580	64	68,3	70,3	67,5
7	12	540	69,7	71	68,6	69,7
8	12	560	71,7	68	74,3	71,3
9	12	580	70,6	72	75	72,5

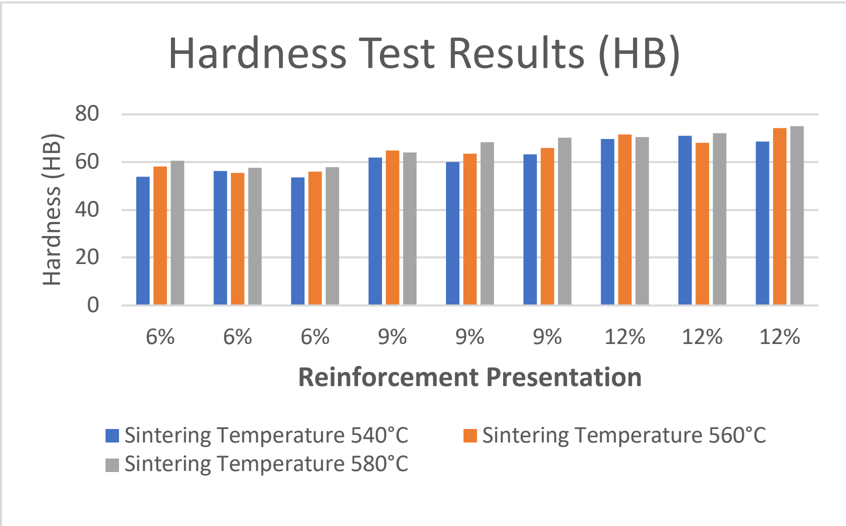


Figure 7. The graphic of the density test results

- Analysis of Variance Hardnes

$$SS_A = \frac{1}{9} \times \frac{((54 + 58,3 + \cdots + 58)^2 + (62 + 65 + \cdots + 70,3)^2 + (69,7 + 71,7 + \cdots + 75)^2)}{9} - \frac{1733,5^2}{27}$$
$$= 954,11$$

$$SS_B = \frac{1}{9} \times \frac{((54 + 56,3 + \cdots + 68,6)^2 + (58,3 + 55,6 + \cdots + 74,3)^2 + (60,6 + 57,6 + \cdots + 75)^2)}{9}$$
$$- \frac{1733,5^2}{27} = 76,78$$

$$SS_{AB} = (54^2 + 56,3^2 + \cdots + 75^2) - \frac{1733,5^2}{27} - 0,58403 - 0,06386 = 8,21$$

$$SS_T = (54^2 + 56,3^2 + 53,7^2 + \cdots + 75^2) - \frac{1733,5^2}{27} = 1116,25$$

$$SS_E = 1116,25 - 954,11 - 76,78 - 8,21 = 77,15$$

The results of calculating the sum of squares were entered into the ANOVA table for further analysis. Table 8 includes the sum of squares for factors A (reinforcement presentation) and B (sintering temperature), the interaction between the two, and the error. The sum of squares calculates the values of degrees of freedom, mean square, and F-value. The F-value is used to assess the significance of the effect of each factor and its interaction with the response variable. This process helps explain the extent to which the applied model can describe the variability of the data.

Table 8. Analysis of Variance Hardness

Source of Variation	SS	Df	MS	F_{value}	F_{table}
A	954,11	2	477,055	111,30	3,55
B	76,78	2	38,389	8,96	3,55
AB	8,21	4	2,052	0,48	2,93
Error	77,15	18	4,286		
Total	1116,25	26			

Based on Table 8, the decision and conclusion of the analysis of variance (ANOVA) are as follows:

Hypothesis:

1. For the variable factor of material composition:
   - H0: There is no significant effect of reinforcement presentation factor on hardness value.
   - H1: The reinforcement presentation factors significantly influence the hardness value.
2. For variable factors of sintering temperature:
   - H0: No significant influence of the sintering temperature factor on hardness value exists.
   - H1: The sintering temperature factor significantly influences the hardness value.

Decision:

Level of significance**:** The significance level used is 5% or 0.05. Based on Table 4, the factorial design ANOVA results show that the calculated F value for the percentage of reinforcement is greater than the F table value. The calculated F value for the percentage of reinforcement is 111.30, while the F table value is 3.55. Thus, the decision is that H1 fails to be rejected, which means that the percentage of reinforcement significantly affects the hardness value of the composite. Furthermore, the calculated F value for the sintering temperature is greater than the F table value. The calculated F value for the sintering temperature is 8.96, with the same F table value of 3.55. This result also shows that the decision H1 fails to be rejected, meaning the sintering temperature treatment significantly affects the value.

Furthermore, the interaction between percentage and sintering temperature treatment shows that the calculated F value is smaller than the F table value. The calculated F value for the interaction between these two factors is 0.48, with an F table value of 2.93. Based on these results, the decision is that H0 fails to be rejected, meaning that the interaction between the percentage of reinforcement and sintering temperature has no significant effect on the hardness value. This ANOVA concludes that both the reinforcement percentage and sintering temperature significantly affect the hardness tested. In contrast, the interaction between reinforcement percentage and sintering temperature significantly does not affect the hardness values.

4. Conclusion

In this study, aluminium matrix composites reinforced with silica alloys and agricultural waste from the powder metallurgy process can affect the resulting density and hardness values because the difference in sintering temperature can produce stronger inter-particle bonds and pores that increase in density so that the density and hardness values are high. Data on the density and hardness values of aluminium matrix composites show the highest average value is 2.308 g/cm³ and 72.5HB, achieved with a reinforcement percentage of 88% Al: 12% (SiO_2, RHA, BA), which was treated with a sintering temperature of 580°C. On the other hand, the lowest average density value of 1.781 g/cm³ and the lowest average hardness value of 54.6HB were recorded for the reinforcement percentage of 92% Al: 12% (SiO_2, RHA, BA) sintered at 540°C. Both factors were studied based on the results of the Analysis of Variance (ANOVA) on the density and hardness data. Namely, the percentage of reinforcement and the sintering temperature itself significantly affected the tensile strength of the resulting composites. These results indicate that variations in reinforcing percentage and sintering temperature do not significantly alter the tensile strength of silica alloy and agricultural waste-reinforced composites. Thus, these treatments may not be effective in significantly increasing the density and hardness of the composites.

Reference

[1] F. D. Fitrianto, Y. Estriyanto, and B. Harjanto, “Pemanfaatan Serbuk Tongkol Jagung Sebagai Alternatif Bahan Friksi Kampas Rem Non-Asbestos Sepeda Motor,” 2013., Corpus ID: 135624818. https://onesearch.id/Record/IOS5828.1337/Preview.

[2] U.D. Idrisa, V.S.Aigbodionb, I. J. Abubakar, and C. I. Nwoyed, “Eco-friendly asbestos freebrake-pad: Using banana peels,” *Polymers (Basel).*, *J. King Saud Univ.-Eng. Sci*, vol. 27, no. 2, pp. 185–192, 2015, http://dx.doi.org/10.1016/j.jksues.2013.06.006.

[3] M. H. Alamsyah, and G. Gundara, “Analisis Sifat Mekanik Komposit Bahan Kampas Rem dengan Penguat Serbuk Kayu Jati dan Serbuk Kuningan,” *J. R.E.M. (Rekayasa Energi Manufaktur)*, vol. 5, no. 1, pp. 9–13, 2020, DOI:10.21070/r.e.m.v5i1.870.

[4] S. Rienera, I. A. Wahyudie, and B. Rollastin, “Effect of Citronella Fiber Treatment On Tensile Strength of Polyester Matrix Composites: A 2k Factorial Design Analysis,” *J. Mechanical of Energy System,* vol. 1, no, 1 pp. 1–9, 2024, https://journal.unesa.ac.id/index.php/jmes/article/view/35335.

[5] H.Sukma, R. Prasetyani, D. Rahmalina, and R. Imanuddin, “Peran Penguat Partikel Alumina Dan Silikon Karbida Terhadap Kekerasan Material Komposit Matriks Aluminium,” *Seminar Nasional Sains dan Teknologi Universitas Muhammadiyah Jakarta*, 2015., https://jurnal.umj.ac.id/index.php/semnastek/article/view/483/449.

[6] L. H. haq, and S. M. B. Respati, “Pengaruh Kandungan Alumina Pada Al-Al_2O_3 Komposit Dengan Metode Penegcoran Sqezze Terhadap UjiTarik Dan Uji Mikro,” *J. Momentum*, vol. 13, no. 2, pp. 30–35, 2017., https://publikasiilmiah.unwahas.ac.id/MOMENTUM/article/view/2033.

[7] Sukarman, and R. A. Gani, “Lahan Bekas Tambang Timah di Pulau Bangka dan Belitung, Indonesia dan Kesesuaiannya untuk Komoditas Pertanian,” *J. Tanah dan Iklim,* vol. 41, no. 2, pp. 101–112, 2017., https://www.researchgate.net/publication/323390912.

[8] C. Suryanarayana, “Mechanical Alloying: A Novel Technique to Synthesize Advanced Materials,” *J. Research*, vol. 2019, https://spj.science.org/doi/10.34133/2019/4219812.

[9] G. S. Gehlen, A. P. G. Nogueira, D. Carlevaris, , L. Y. Barros, J. C. Poletto, G. Lasch, G. Straffelini, N. F. Ferreira, and P. D. Neis, “Tribological Assessment of Rice Husk Ash in Eco Friendly Brake Friction Materials,” *Wear*, vol. 516–517, 2023, https://doi.org/10.1016/j.wear.2022.204613.

[10] Sriatun, Taslimah, and Linda Suyati, “Synthesis of Zeolite from Sugarcane Bagasse Ash Using Cetyltrimethylammonium Bromide as Structure Directing Agent,” *Mater. Eng. Res.*, vol. 1, no. 2, pp. 86–97, 2019, https://jurnal.ugm.ac.id/ijc/article/view/22197.

[11] M. Mukhlis, W. Hardi, and R. Mustafa, “The Effect of Treatment of Coconut Fiber with Liquid Smoke on Mechanical Properties of Composite,” *J. Indones. J. Chem.*, vol. 18, no. 1 pp. 159–165, 2018, DOI:10.1051/e3sconf/202132807010.

[12] S. E. Susilowati, A. Fudholi, and D. Sumardiyanto, “Mechanical and Microstructural Characteristics of Cu–Sn–Zn/ Gr Metal Matrix Composites Processed by Powder Metallurgy for Bearing Materials,” *Results Eng.*, vol. 14, no. February, p. 100377, 2022, https://www.sciencedirect.com/science/article/pii/S2590123022000470.

[13] M. Syahid, A. Hayat, and Aswar, “Effect of Graphite Addition on Aluminum Hybrid Matrix Composite by Powder Metallurgy Method,” *Rev. des Compos. des Mater. Av. Compos. Adv. Mater.*, vol. 32, no. 3, pp. 125–132, 2022, https://www.iieta.org/journals/rcma/paper/10.18280/rcma.320303.

[14] A. G. Dylan, Sugiyarto, A. Wanto, A. Budi, and Sukanto, “Pembuatan Komposit Matrik Aluminium Diperkuat Silicon Carbida Dan Rice Husk Ash Dengan Metode Metalurgi Serbuk,” *J. LONTAR*, vol. 10, no. 2, pp. 65–74, 2023., https://ejurnal.undana.ac.id/LJTMU/article/view/13481.

[15] Y. Anggreni, Sugiyarto, A. Rusdy, I. A. Wahyudie, Rodika, Y. Oktriadi, and Sukanto, “Pembuatan Komposit AMC Hybrid Baggase Ash dan Alumina Metode Metalurgi Serbuk,” *J. Dinamika*, vol. 8, no. 2, pp. 125–132, 2023, https://ejournal.unkhair.ac.id/index.php/Dinamik/article/view/7034.

[16] Anon, “AlSi10Mg Alloy.” *Bayvillechemical.net*, 2024, www.bayvillechemical.net/alsi10mg-alloy.

[17] Wikipedia Contributors. Aluminium [Internet]. Wikipedia. Wikimedia Foundation; 2019. Available from: https://en.wikipedia.org/wiki/Aluminium.

[18] Wahyono Suprapto. Baja dan Aplikasinya. Universitas Brawijaya Press; 2015;

https://digilib.ub.ac.id/opac/detail-opac?id=80211.

[19] ASTM International, “Standard Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes’ Principle,” Astm B962-17, vol. i, pp. 1–7, 2017, doi: 10.1520/B0962-17.2.

[20] ASTM E110-14, “Standard Test Method for Rockwell and Brinell Hardness of Metallic Materials by Portable Hardness Testers,” ASTM B. Stand., pp. 1–5, 2014, doi: 10.1520/E0110-14.2.